

ADVANCED CO₂ CYCLE POWER GENERATION

QUARTERLY TECHNICAL PROGRESS REPORT
OCTOBER 1, 2003 THROUGH DECEMBER 2003

By

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January 2004

Work Performed Under Contract: DE-FC26-02NT41621

For

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory
Morgantown, West Virginia

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**TECHNICAL PROGRESS REPORT NUMBER 41621R04
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Abstract

Research is being conducted under United States Department of Energy (DOE) Contract DE-FC26-02NT41621 to develop a conceptual design and determine the performance characteristics of a new IGCC plant configuration that facilitates CO₂ removal for sequestration. This new configuration will be designed to achieve CO₂ sequestration without the need for water gas shifting and CO₂ separation, and may eliminate the need for a separate sequestration compressor.

This research introduces a novel concept of using CO₂ as a working fluid for an advanced coal gasification based power generation system, where it generates power with high system efficiency while concentrating CO₂ for sequestration. This project supports the DOE research objective of development of concepts for the capture and storage of CO₂.

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1. Executive Summary

Project Overview

The linkage between global climate change and emission of greenhouse gases such as carbon dioxide (CO₂) is well documented. Modern pulverized coal-fired power plants are some of the largest single point emitters of CO₂. To assure continued U.S. power generation from its abundant domestic coal resources, new coal combustion technologies must be developed to meet future emissions standards, especially CO₂ sequestration.

This project will develop a conceptual design to determine the performance characteristics of a new IGCC plant configuration that facilitates CO₂ removal for sequestration without the need for water gas shifting and CO₂ separation and may eliminate the need for a separate sequestration compressor. The plant will introduce a novel concept of using CO₂ as a working fluid for an advanced coal gasification based power generation system, where it generates power with high system efficiency while concentrating CO₂ for sequestration. This project supports the DOE research objective of development of concepts for the capture and storage of CO₂.

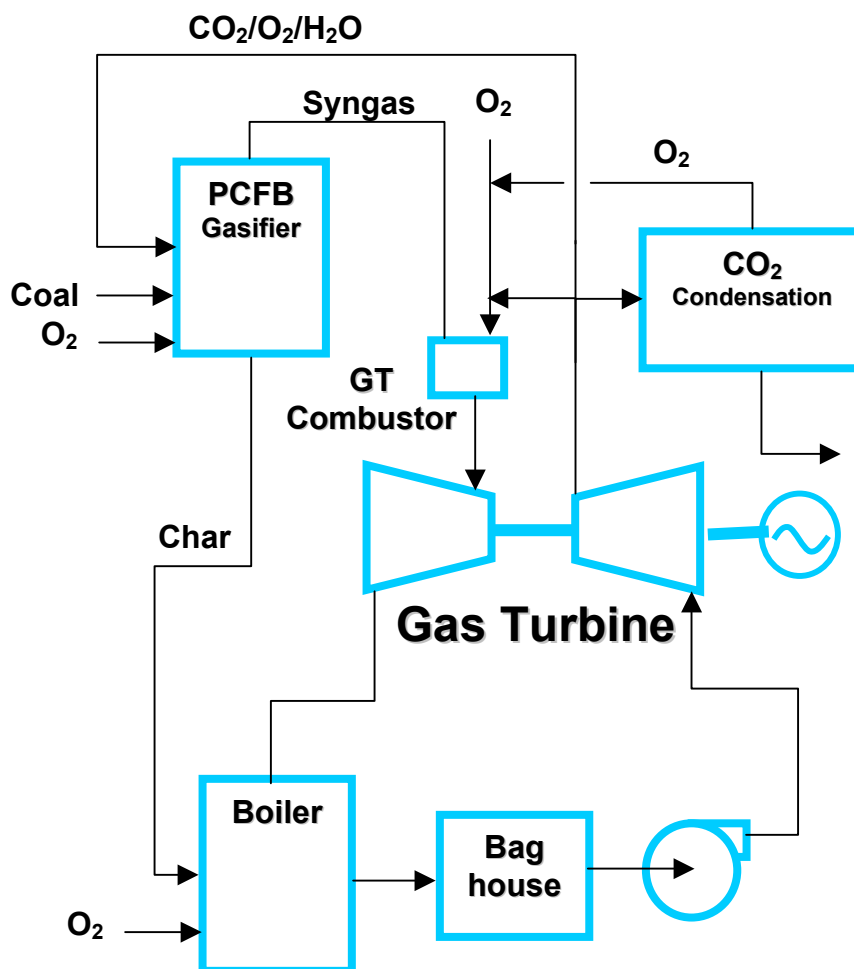
A published study^{[1]*} has shown that CO₂ removal/sequestration systems applied to the back end of a pulverized coal-fired plant can reduce its efficiency by up to 11 points with a resulting \$30 per ton CO₂ removal cost. For oxygen-blown IGCC plants, carbon monoxide can be water gas shifted to hydrogen and CO₂ upstream of the gas turbine. The CO₂ can then be separated and concentrated by absorption and stripping or by membranes and then compressed for sequestration. This process is energy intensive, costly, and lowers system efficiency due to the energy losses associated with shifting. (Because the lower heating value (LHV) of hydrogen is less than carbon monoxide on a per mole basis, 15% of the LHV is lost when carbon monoxide is shifted to hydrogen. Therefore, more syngas needs to be generated from gasification to compensate for the shift loss. The low-grade heat from the shift reaction contributes to system losses.) An efficiency loss of 6% with a CO₂ removal cost of \$15 per ton is estimated for such an IGCC plant.

The proposed advanced gasification system avoids these problems by using a mixture of CO₂ recycled from the gas turbine exhaust together with oxygen as the working fluid; this facilitates straightforward concentration of CO₂ at high pressure without a shift reaction and, depending upon the required pipeline pressure, may eliminate the need for a separate compressor for sequestration. Any excess oxygen in the gas turbine exhaust is recycled along with the CO₂ back to the gasifier, thus minimizing oxygen usage. The process eliminates the need for CO₂ shifting, absorption, and stripping allowing direct collection of CO₂ at the gas turbine compressor discharge pressure. This results in a simpler CO₂ collection process than conventional oxygen-blown IGCC systems while providing additional advantages of a lower cost and a minimal loss in efficiency.

* numbers in brackets indicate reference

A simplified schematic of the process is shown below in Figure 1.

Figure 1. Process Schematic



Progress During the Quarter (October 1 through December 2003)

During this quarter, efforts were concentrated on Task 2: Gasifier and Char Combustor Design. Based on the plant conceptual design and detailed cycle analyses completed during the previous quarters the overall system design parameters were identified. These parameters, shown on Table 1, were then used for the detailed design of the gasifier and the char combustor.

The gasifier will utilize Foster Wheeler's circulating fluid bed technology for highest fuel flexibility, scalability, and operational simplicity. Operating at 850 psig, it will be a compact unit at just 4ft in internal diameter for 13 ft/sec nominal superficial gas velocity. Coal will be fed at the base of the unit along with oxygen, recycle CO₂, and process steam. A cyclone and solids return leg will recycle solids back to the base of the gasifier to maintain temperature uniformity throughout the gasifier and to enhance carbon conversion rates. Coal and char particles will travel up the riser through a height of 80 ft, which will provide a residence time of about 6 seconds.

The gasifier will generate about 575 klb/hr of syngas for the topping cycle and 69 klbs/hr of char to be burned in the char combustor. The syngas will be generated at about 1950 degrees F. A fire-tube type syngas cooler will be used to bring this temperature down to about 650 degrees F so that the syngas can be put through sintered metal filters for fine particulate removal before it is burned in the gas turbine combustor. An elevation drawing of the gasifier is shown on Figure 2.

The char combustor will utilize Foster Wheeler's circulating fluidized bed combustion technology. It will generate 1300 klbs/hr of supercritical steam at 3850 psig and 1040 degrees F. This steam will then go through the HP stages of the steam turbine. The HP section discharge will combine with about 225 klbs/hr of intermediate pressure steam generated by the gasifier syngas cooler. The combination, about 1525 klbs/hr of steam, will return to the reheat section of the CFB char combustor. Reheater outlet steam will be at 830 psig and 1050 degrees F.

The CFB furnace, with its major dimensions, is shown on Figure 3. The main furnace section will be 58 ft wide by 28 ft deep. The overall height of the structure will be about 236 ft from grade. The design will feature wing wall superheaters as well as in-duct HRA superheaters.

Task 3 – Balance of Plant Design and Plant Cost Estimating will commence shortly.

Table 1: System Design Parameters. Fuel Basis: Illinois #6 Coal.

Air Separation Unit	
Oxygen Yield, klb/hr	506
Power Consumed, MW	52
Gasifier	
Coal Feed Rate, klb/hr	190
Oxygen Usage, klb/hr	91
Process Steam Usage, klb/hr	15
CO ₂ Feed Rate, klb/hr	348
Syngas Yield, klb/hr	577
Lower Heating Value of Syngas, btu/scf	159
Syngas Cooler Duty, MMbtu/hr	283
Char Yield, klb/hr	69
Gas Turbine	
Power Output, MW	107
Turbine Inlet Temperature, F	2225
Exhaust Gas Flowrate, klb/hr	2091
Exhaust Gas Temperature, F	1137
Boiler	
Coal Feed Rate, klb/hr	54
Flue Gas, klb/hr	2443
Main Steam Flowrate, klb/hr	1300
Main Steam Temperature, F	1040
Main Steam Pressure, psig	3850
Reheat Steam Flowrate ¹ , klb/hr	1525
Reheat Steam Temperature, F	1050
Reheat Steam Pressure, psig	830
Steam Turbine	
Power Output, MW	281

¹ Includes IP steam generated by the gasifier syngas cooler

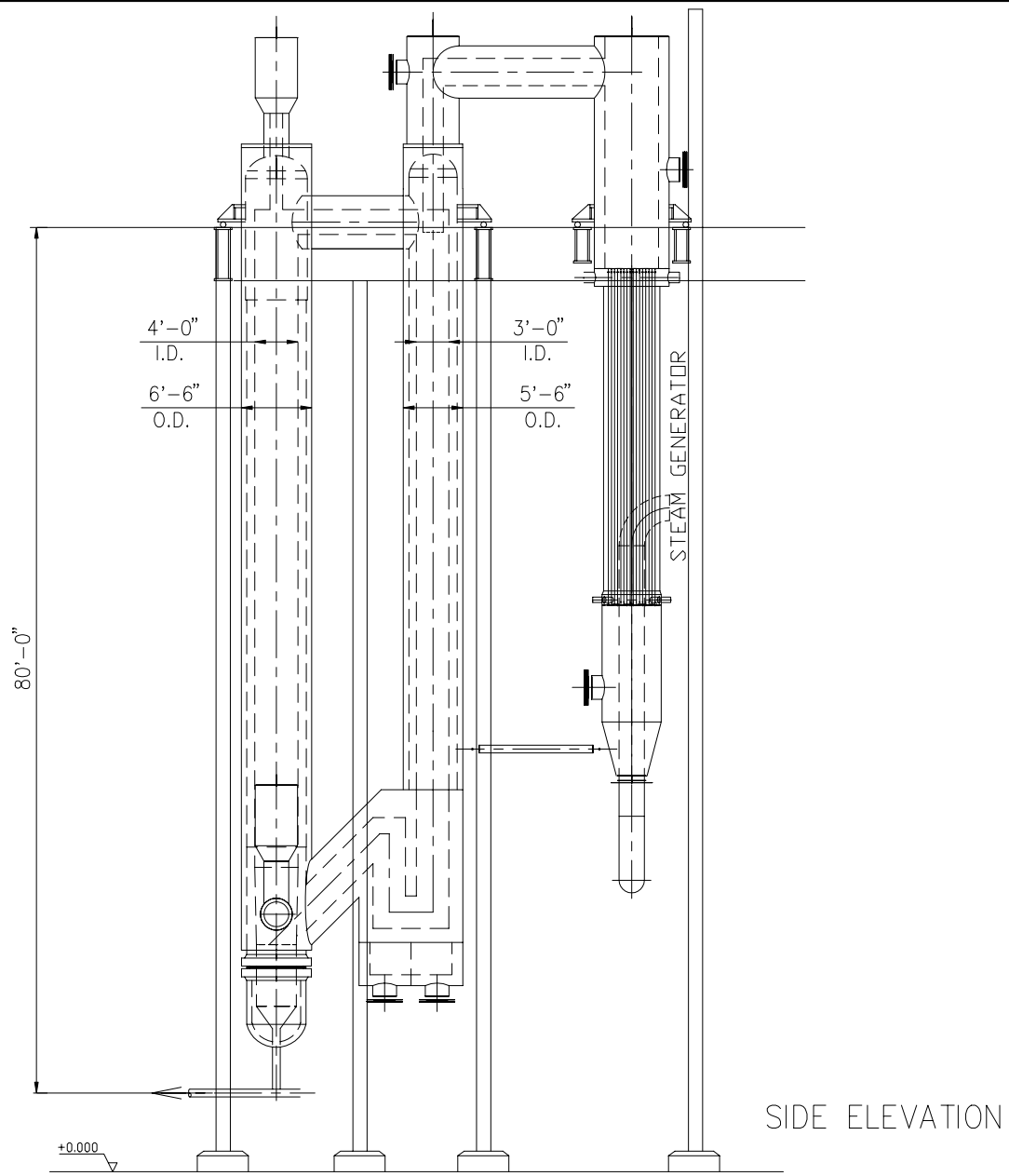
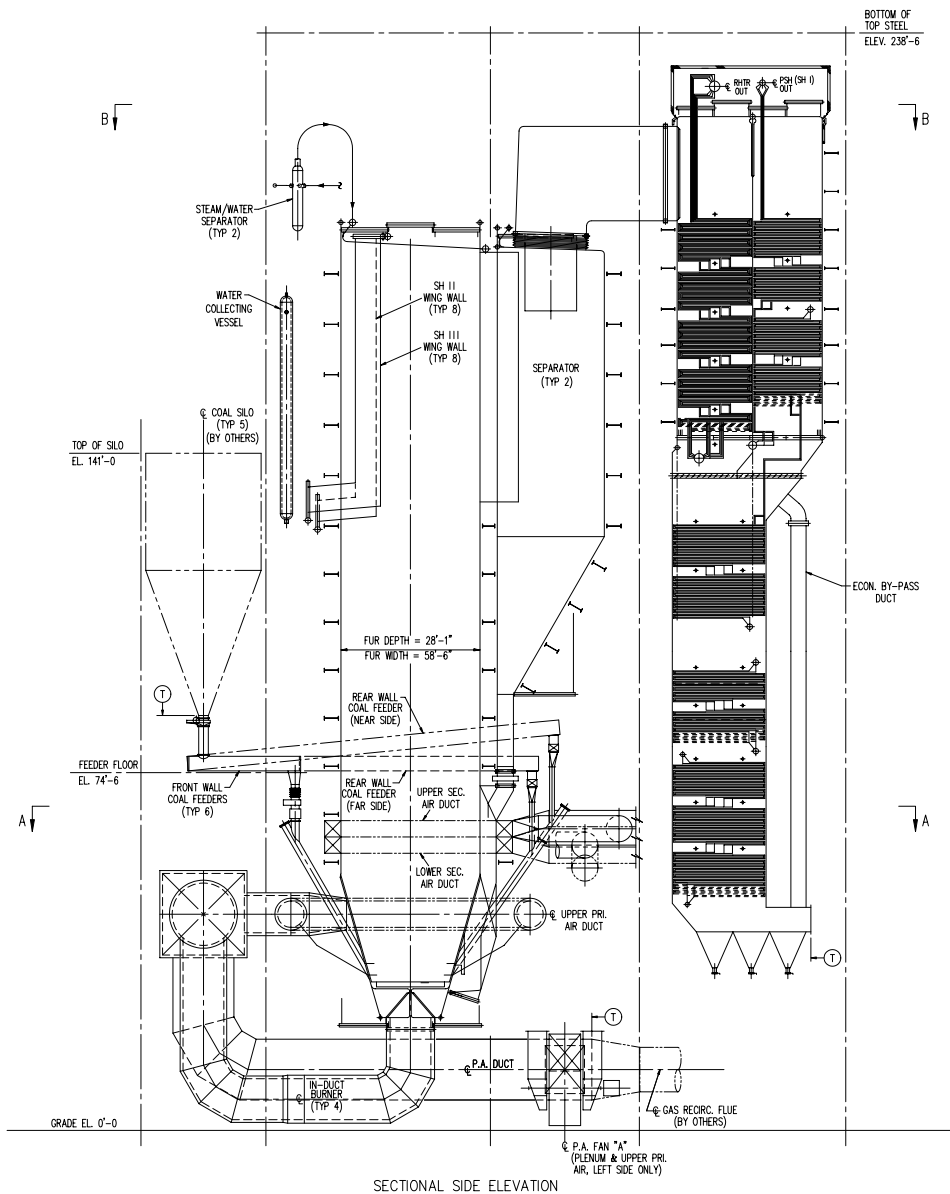
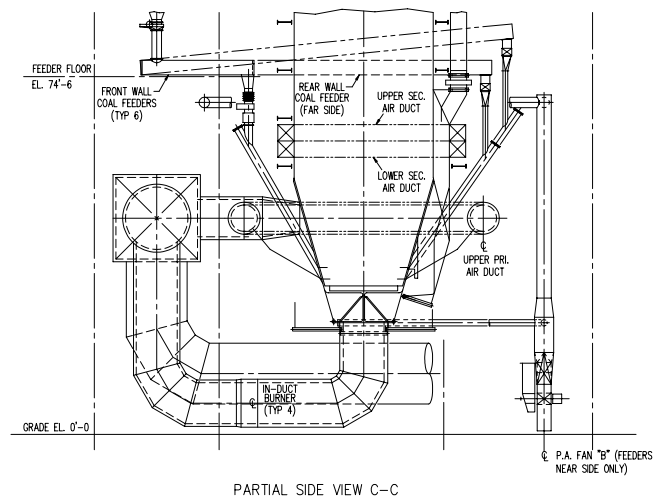


Figure 2. Gasifier Side Elevation



PRELIMINARY CONCEPT
(DO NOT SCALE)



3. IN THE EVENT OF ANY INCONSISTENCIES IN THE SCOPE OF EQUIPMENT BETWEEN THIS DRAWING AND THE TECHNICAL PROPOSAL, THE TECHNICAL PROPOSAL SHALL GOVERN.
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5. ① INDICATES FWEC TERMINATES HERE.
6. ● INDICATES FULL RETRACT SOOTBLOWERS.
7. ⚙ INDICATES ROTARY SOOTBLOWERS.

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Figure 3. CFB Elevation View

2. Experimental

This work is a conceptual study and does not employ any experimental methods.

3. Results and Discussion

One of the challenges of this design exercise was to make sure that the system could be started-up safely and reliably, and to provide for certain contingencies such as stand-alone operation. A proper economic evaluation cannot be made without accounting for equipment that may not be used during normal, combined cycle, operation but is crucial to system availability.

Since the steam cycle is the heat sink for the GT combustor, the CFB has to be started up first. Also, for maximum system availability, it was decided that the CFB should have standalone operating capability (operation without the gasifier and/or the gas turbine running). As a result, a full flow gas recirculation fan was deemed necessary to recycle flue gas ($\text{CO}_2/\text{O}_2/\text{H}_2\text{O}$) back to the furnace for temperature control. A small start-up stack (roughly 15% of full exhaust flow) will be provided to purge the furnace of air before start-up.

Stand alone operating capability for the topping cycle (gasifier and gas turbine) was considered but found to be greatly inefficient and capital intensive without a sink for the hot exhaust gases, which must be cooled before the CO_2 can be sequestered.

4. Conclusions

No technical project conclusions are currently available.

5. References

1. "Evaluation of Innovative Fossil Cycles Incorporating CO_2 Removal", M. De Lallo et al, Parsons Energy and Chemical Group. Presented at 2000 Gasification Technologies Conference, San Francisco, CA, October 8-11, 2000.